NATIONAL BUREAU OF STANDARDS REPORT

5353

QUARTERLY REPORT

ON

EVALUATION OF REFRACTORY QUALITIES OF CONCRETES FOR JET AIRCRAFT WARM-UP, POWER CHECK, MAINTENANCE APRONS, AND RUNWAYS

by

W. L. Pendergast, E. C. Tuma, L. E. Mong
and E. Trattner

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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NBS PROJECT | **NBS REPORT**

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Refractories Section
Mineral Products Division

Sponsored by

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Bureau of Yards and Docks

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Approved:
Dr. Samuel Zerfoss
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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

QUARTERLY REPORT
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EVALUATION OF REFRACTORY QUALITIES OF CONCRETES FOR JET AIRCRAFT WARM-UP, POWER CHECK, MAINTENANCE APRONS, AND RUNWAYS

1. INTRODUCTION

This phase of the project includes the determination of the cause or causes of failure that occur in concrete aprons and runways exposed to jet exhaust gases. A combustion chamber that delivers hot gases at velocities and temperatures approximating those of field conditions is being used. The approach includes instrumentation of the concrete test panels to determine the heat gradients and stresses set up during flame impingement at several locations on the test area and at varying depths below the surface.

2. ACTIVITIES

2.1 Pressure Developed in Concrete During Heating

The apparatus which consisted of a bomb, pressure gage, and connecting fittings made entirely of stainless steel, shown in Figure 2, N.B.S. Report 5233, April 15, 1957, was used in the tests during this quarter.

The first three heating cycles were made with the bomb charged with neat portland cement, cured 10 days in the fog-room, and dried under vacuum at room temperature. In these tests a second lot of silicone oil was used to transmit the pressures. The maximum pressure developed during the first heating was 900 psi, 800 psi in the second, and 750 psi in the third. Residual pressures on cooling to room temperature

were 150, 135, and 50 psi respectively. These pressures were relieved before the succeeding test. An analysis of the gas causing this residual pressure gave 0.8% CO_2, 0.8% O_2, and no CO. The remainder of the gas was combustible and was probably some form of hydrocarbon derived from the new lot of silicone oil. Since this oil proved to be unstable it was decided to use mercury as the pressure transmitting liquid.

The second bomb charged with water only and mercury as the transmitter was given two heating cycles. During the first of these heating cycles abnormally high pressures developed due to the differential thermal expansion of the bomb and its contents. Before the second heating cycle a necessary amount of mercury was removed and the resulting pressure-temperature curve was similar to the steam tables.

The third bomb contained neat portland cement, fog-room cured for 45 days, and dried at room temperature under vacuum. The results of the three heating cycles on this bomb agreed. This agreement indicates that possible alteration in the mineralogical composition of the cement did not seriously effect the pressure-temperature relation. Deviation from the steam tables were observed for temperatures below 200°C but were not present above this temperature. This deviation in the lower region (100-200°C) indicated that, on heating, higher temperatures were required than those given in the steam tables; while on cooling the opposite was true. This deviation may indicate that chemical bonding of water is a

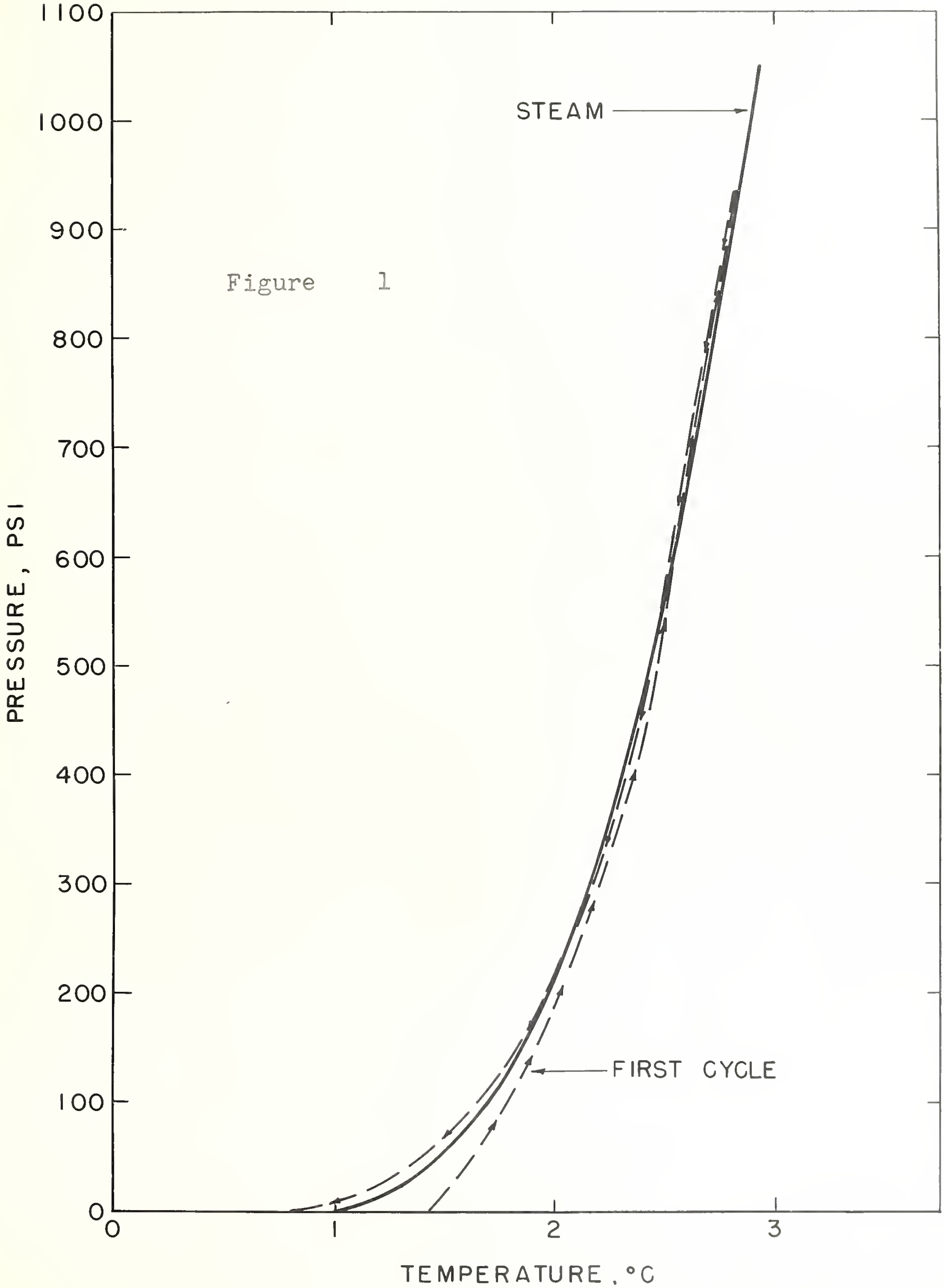
factor in the temperature-pressure relations at the lower temperatures. The extent of this effect, amounted to a maximum temperature alteration of but 17°C. A graph of the temperature-pressure relation for the first heating cycle is shown in Figure 1.

Samples of the neat cement were taken for X-ray examination following the third heating cycle, after drying at 110°C, and after heating at 350°C.

A third bomb was charged with brick aggregate and water, equivalent to that amount used as mixing-water for concrete. The pressure-temperature relation during a heating cycle coincided very closely with the steam curve.

A fourth bomb contained concrete designed with brick aggregate and portland cement, fog-room cured for 15 days with no drying treatment. The pressure-temperature curve for the heating cycle was similar to that shown in Figure 1.

Inasmuch as the thermocouple located at the middle of the charge was sometimes erratic due to the presence of mercury and occasionally imperfect insulation the use of this thermocouple was discontinued. The temperature measurements can be made with sufficient accuracy by means of a thermocouple attached to the outside of the bomb for the heating rates used (50°C per hour). The use of the external thermocouple only will also enable us to obtain weight changes of the bomb contents following various heat treatments.


1100
1000
900
800
700
600
500
400
300
200
100
0
PRESSURE, PSI
0
1
2
3
TEMPERATURE, °C
STEAM
FIRST CYCLE
Figure 1

The pressure-temperature curves shown in Figures 3 and 4 of N.B.S. Report 5233 were probably in error due to the unknown properties and reactions of the silicone oil.

The data on the neat portland cement, brick aggregate, and concrete designed using these constituents indicate that pressure, equivalent to the desired strength, (650 psi) would be developed in concrete at temperatures in the vicinity of 250°C. Inasmuch as the strength of the concrete decreases as the temperatures of exposure increases the developed steam pressure could be expected to fracture the concrete at temperatures below 250°C unless a means of egress for the steam is available. Some fractures, evidenced by abrupt changes in temperatures of buried thermocouples, shown in Figure 2, N.B.S. Report 4767, July 20, 1956, occurred in the range 225 to 325°C. The fractures, occurring at higher temperatures, ranging to 500°C, Figures 2 and 3 of the same report, may have been delayed due to moisture loss through the concrete.

Bombs charged with Lumnite or Alcoa XCA-25 high-alumina hydraulic cements have been prepared. It is possible that these cements may perform more advantageously in the bomb test.

The thermal length changes of the comparatively pure high-alumina hydraulic cement (Alcoa XCA-25) cured 28 days in fog-room and dried 14 days at 35 percent relative humidity at 77°F is shown in Figure 2.[1/] Below 1000°C the length

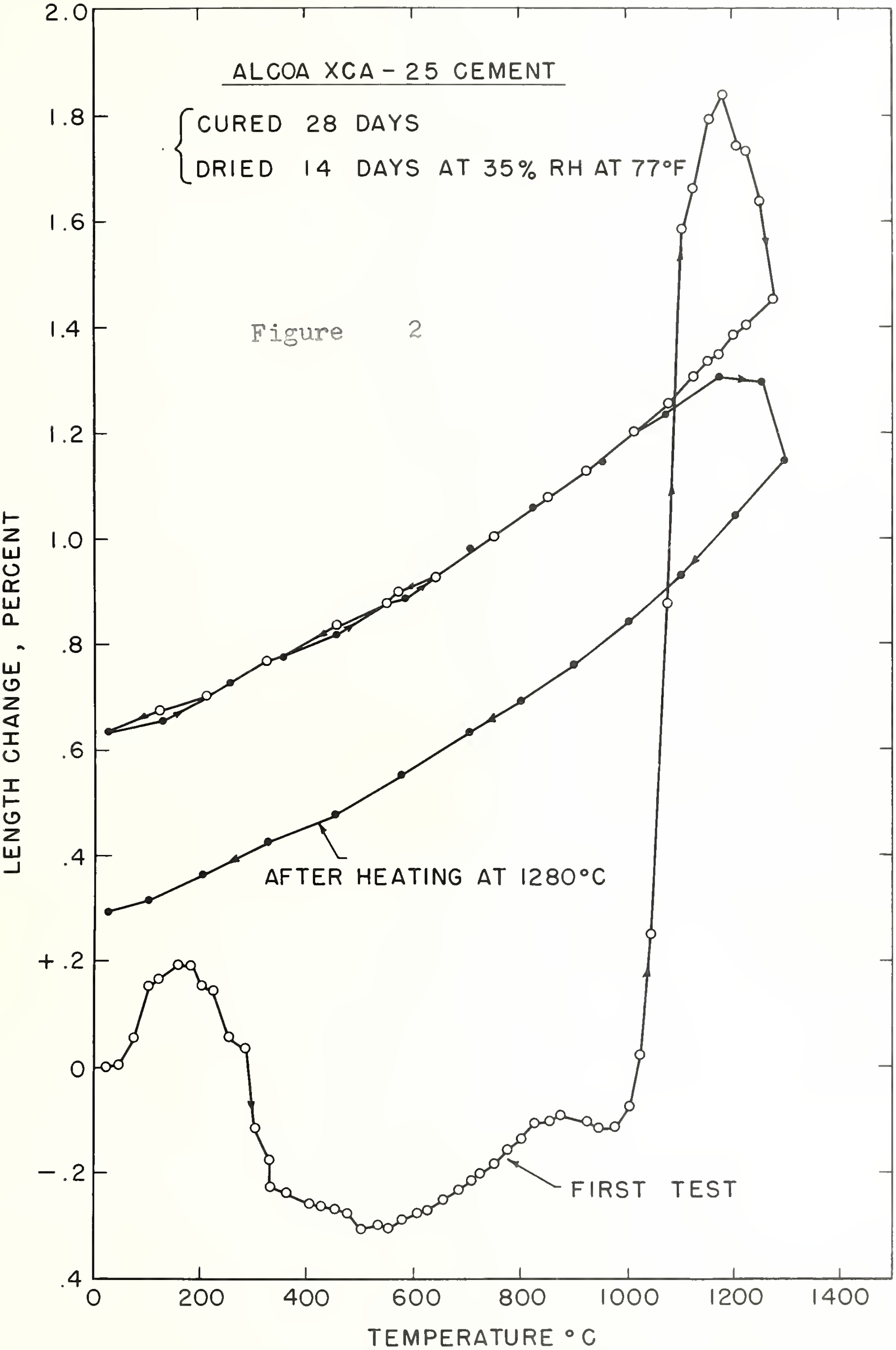
[1/] Determined by S. Schneider, Refractories Section.

changes are comparatively small and differ markedly, from the other cements included in this project, in that a large expansion occurs between 1000 and 1180°C for the cured cement. This inflection was absent in the cooling curve and the expansion and contraction curves of the material after heating to 1280°C. This inflection would not be involved in considering its use for jet aprons.

2.2 Jet Impingement Tests

The results of the jet impingement tests on ten panels having diabase aggregate are given in Table I. The second lot, P-D_i-2 were duplicates of P-D_i-1. Panels 1, 2, and 3 of the second lot were tested after short drying periods and had considerably larger losses in the test than those dried for longer periods. Larger losses occurred in the second lot as shown by the comparison of P-D_i-2-4 to P-D_i-1-1 and 2, and of P-D_i-2-5 to P-D_i-1-5. Such differences in results could be attributed to experimental errors.

The three panels Al-B-3 were designed with Alcoa (XCA-25) cement and crushed building brick aggregate were outstanding because they show no loss after 5, 10, or 15 minutes exposure after relatively short drying periods of 7, 14, and 28 days. An analysis of the recorded temperatures (at six locations) taken from these panels indicated that the temperature for corresponding locations in P-D_i-1 and P-D_i-2 panels were in fair agreement. The comparison is limited by the large variation in temperature at the same location for the five


ALCOA XCA - 25 CEMENT
CURED 28 DAYS
DRIED 14 DAYS AT 35% RH AT 77°F
Figure 2
AFTER HEATING AT 1280°C
FIRST TEST
LENGTH CHANGE, PERCENT
TEMPERATURE °C
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
+.2
0
-.2
.4
0
200
400
600
800
1000
1200
1400

panels of a single lot and also by the possibility of defective thermocouples. The results of the tests on three panels A1-B-3-1, 2, and 3 indicate that the temperature at the center surface of the panels was about 300°C less than that recorded for panels containing portland cement.

The higher thermal conductivity of the Alcoa (XCA-25) may account for this difference. The thermal conductivity of samples of this type concrete will be determined.

2.3 A Study of the Mechanism by which Water Vapor Travels Through Concrete

The study of the mechanism by which water vapor travels through concrete, the rate of transfer from a high-pressure to a low-pressure, and the effect of environmental conditions on the rate of transfer, has been continued.

Two flanged cylindrical chambers were constructed, each to maintain different constant relative humidities. A three to four-inch cross-section was cut from a six by twelve-inch concrete cylinder sealed on the outside surface and placed between the two chambers. The section of concrete was sealed with asphalt emulsion and brought to equilibrium by storage in a 75 percent relative humidity atmosphere. Constant relative humidities are maintained in the cylindrical chambers by two small diaphragm pumps that circulate air of a constant relative humidity through the respective chambers. Small sealed plastic containers charged with appropriate salt solutions serve as the source of the selected relative

Table I. Spalling Loss of Panels During Jet Impingement.

Concrete 1/	Panel	Drying Time 2/	Total Water at Time of Test 3/	Time of Exposure 4/	Spalling Loss Calculated From Weight 5/	Spalling Loss Calculated From Volume 6/
		days	%	minutes	cc	cc
$P-D_i-1$	1 7/	28	7.97	5	52.11	93.4
do	2 7/	49	7.59	5	69.67	- 8/
do	3 7/	63	7.37	5	17.27	135.50
do	4 7/	77	7.56	5	58.02	- 8/
do	5	91	7.10	10	19.82	- 8/
$P-D_i-2$	1	14	7.30	5	322.84	464.93
do	2	7	7.23	5	195.12	336.81
do	3	21	7.16	5	323.98	547.96
do	4	35	6.83	5	126.02	395.92
do	5	112	6.80	5	42.70	- 8/
Al-B-3	1	7 9/	9.64	5	- 8/	- 8/
do	2	14 9/	9.56	10	- 8/	- 8/
do	3	28 9/	9.46	15	- 8/	- 8/

1/ The first letters; P=portland cement; AL=Alcoa XCA-25, a high-alumina hydraulic cement. The second letters; D_i=diabase aggregate; B=crushed building brick aggregate. The numerals indicate the batch.

2/ Days stored at 73°F and 50 percent relative humidity sealed on all but one (18x18 inch) exposed face.

3/ Mixing water plus that absorbed during curing minus that evaporated during storage.

4/ Exposed to jet stream at 1200°F and velocity of 1200 feet per second.

5/ Calculated from weight loss.

6/ Determined by sand volume method.

7/ Appeared in NBS Report 5233, Table I.

8/ No visible loss.

9/ Fog-room cured for 14 days only. All concretes designed with portland cement were cured for 28 days.

humidity and the small pumps convey the atmosphere from these plastic containers to larger cylindrical chambers. At regular time-intervals the plastic containers, together with their contents, are weighed and the gain or loss in weight is noted. When the loss in weight on the one side equals the gain in weight on the other the concrete has reached equilibrium, that is, the concrete is under a higher realtive humidity (75 percent) on one side and a lower relative humidity condition on the other. At this point the rate of vapor transfer under given conditions can be established. For this series of tests concrete cylinders of three different cement contents were cast, and are being cured in the fog-room, to be used as needed. The difference of rate of transfer through a high, medium, and low strength concrete will be studied.

This apparatus, with modifications, will be used to study the rate of transfer of neon gas through wet and dry concrete. Assuming that neon gas is not adsorbed by concrete at room temperature the difference in rates of transfer will make it possible to estimate how much of the vapor transfer is due to gaseous diffusion and how much to some other mechanism.

3. OCCURRENCE OF DIABASE

A review of the literature describing the location, extent of the deposite, petrograph analysis, and chemical analysis of diabase throughout the country is underway. If possible

samples will be obtained from various parts of the country and examined. The results of such an examination will assist in preparing specification for this material as an aggregate.

4. LITERATURE

A review of the following articles was made during this quarter:

/ 1 / "Properties of Some Calcium Aluminate Cement Compositions," Gitzen, Hart, MacZura, Journal American Ceramic Society, Vol. 40, No. 5, May 1957.

Abstract

The properties of some high-purity calcium aluminate cement compositions in that portion of the lime-alumina system from 64 to 86 percent alumina were investigated. The laboratory preparation of seven hydraulic compositions in this system is described. Methods of appraising the properties, both in the neat cement and in castable formations, are given. Data on bond strength, setting properties, heat of hydration, refractoriness, and aging characteristics are presented. A cement composition represented by the empirical molar formula $CaO \cdot 2.5Al_2O_3$ was found to be optimum for balanced bond strength and refractoriness in high-temperature castables.

/ 2 / "Phosphate-Bonded Alumina Castables: Some Properties and Applications," Gitzen, Hart, MacZura, American Ceramic Society Bulletin, June 1956.

Abstract

Refractory castables composed of a sintered aluminum oxide grog bonded with phosphoric acid have been developed and tested. Both heat-setting and cold-setting compositions are described. These castables are characterized by high bond strength which is developed at 650°F and remarkable resistance to erosion over a wide temperature range. The influence of thermal shock and phase inversions on bond strength was investigated. Castable preparations, methods of placement and curing procedures are discussed. Data collected from several field applications indicate excellent serviceability of these castables in the temperature range of 3400°F.

/ 3 / "Structural Refractory Concrete," Herman G. Protze, Journal American Concrete Institute, Vol. 28, No. 9, March 1957.

Abstract

Theoretical and practical problems in the construction of jet engine test cell exhaust structures are considered including the development and use of proper materials, mixtures, equipment, and methods of installation of durable

structural refractory lightweight aluminous cement concretes. The author draws from laboratory and field experiences on four projects in recommending current optimum tehcniques for such work.

5. CONFERENCES

A conference was held at this Bureau, April 25. The names of those attending follow:

Commander F. C. Hanshe Everet Warner, 11th Naval District L. A. Palmer P. Knoop P. P. Brown	Bureau of Yards and Docks
I. C. Schoonover S. Zerfoss Bruce Foster William Pendergast	National Bureau of Standards

The results of the work completed during the first nine months of this fiscal year were reported and discussed.

As a result of the discussion between the research group of the Bureau of Yards and Docks and members of the staff of the National Bureau of Standards it was decided that the following items should be included in the program for the ensuing year.

1. (a) A continuation of the bomb tests on concrete and neat cement to evaluate steam pressures developed at given temperatures.

(b) Modify the pore system of concrete by introducing large connecting pores by methods of fabrication, air entrainment etc without appreciably lowering strength.

2. (a) Correlation of the degree of dryness of concrete with its failure in the jet blast test.

(b) The determination of the amount and distribution of water from humidity measurements within concrete.

3. (a) A study of the mechanism by which water vapor travels through concrete.

4. Identification of concrete susceptible to failure primarily by (a) development of steam pressure, (b) thermal spalling.

Dr. Zerfoss reported briefly on items relevant to this project that were discussed at the last meeting of the Advisory Group, Ohio River Division Laboratories, Corps of Engineers, U. S. Army, formed for the guidance of the study of pavements resistant to the action of jet and rocket exhaust.

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

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WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems. Application Engineering.

- Office of Basic Instrumentation
- Office of Weights and Measures

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering.

Radio Standards. Radio Frequencies. Microwave Frequencies. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.

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